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# EXPERIMENTAL HYPERVELOCITY FIRINGS USING STICK AND GRANULAR PROPELLANT CONFIGURATIONS

CARL R. RUTH
FREDERICK W. ROBBINS
ALBERT W. HORST

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U.S. ARMY LABORATORY COMMAND

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The suitability of lumped-parameter interior ballistic models for prediction of the interior ballistic performance of very high velocity guns is limited by use of a predetermined pressure gradient which is superimposed on the solution to approximate the relationship between space-mean, breech and projectile base pressures. Even modern two-phase flow interior ballistic models, specifically formulated to address the hydrodynamics of the problem, have not been extensively exercised in this regime. Only recently have limited, large-caliber gun firings with realistic projectile masses been conducted to provide required data in this velocity regime. In this study, firings were conducted in a long 120-mm gun at propellant charge to projectile mass ratios (C/M) of about 3 to 6, yielding muzzle velocities in the 2 - 2.7 km/s range. The tube was instrumented with pressure gages at various locations along its length to provide data for comparison to predictions of various interior ballistic codes.

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## 1. BACKGROUND TO THE PROBLEM

There has always existed substantial interest in high muzzle velocities for academic and both indirect and direct military exploitation (Swift 1979; Baer 1982; Powell 1987; Baer 1987; Hertzberg 1988; Thomkins 1988). Many recent discussions focus on electric gun propulsion alternatives (e.g., rail gun, coil gun, electrothermal gun), many of which are purported to circumvent the supposedly all-important limitation of the speed of sound in the propellant gases. Although research and development is proceeding on the above disciplines at various government and private agencies, the point may be made, from a military perspective, that both the payoffs and the system burdens of very high velocities must be carefully scrutinized when considering the practicality of any of the available concepts, be they chemical or electric. Excessive system weights and/or gun wear rates associated with heavy tubes required to support the very high breech pressures associated with the high C/M ratios required to achieve high velocities with conventional guns versus the currently excessive weights associated with power generation (and perhaps cooling) for electric gun concepts may pose the limits of real concern to the gun designer.

Muzzle velocities as high as 3950 m/s have been achieved by Baldini (1985) using solid propellant guns though admittedly at C/M's and pressures too high for practical military applications. Investigators at the Ballistic Research Laboratory (BRL) demonstrated muzzles velocities at 2500 m/s (Ruth and Horst 1988), a somewhat lower but clearly interesting ballistic level with potentially acceptable system burdens. However, propellant and projectile weights were outside the current range of 120-mm components. The current goal is to enlarge the experimental data base by measuring experimentally, the pressure gradient in a solid propellant gun firing at velocities in the 2 to 3 km/s range. Effects of varying both charge and projectile weight to achieve different C/M's, type of propellant (stick versus granular), and propellant conditioning temperature were all parameters to enlarge on the limited existing data base presently available on high velocity chemical systems (Robbins and Keller 1988). A 120-mm, ballistic tube similar to an XM-25 Cannon (1524 cm longer than the standard 120-mm, M256 Cannon) was available for use in this study. Unfortunately, since existing projectile onboard instrumentation/telemetry packages would not withstand the high-acceleration environment (~100 kG's), determination of the pressure gradient had to be made using discrete location pressure gages mounted in the tube sidewall. Preliminary calculations using a standard lumped-parameter interior ballistics code (Anderson and Fickie 1987) suggested that either a 19-perforated JA2 stick or a granular propellant would launch 1.6 to 3.0 kg projectiles to a velocity in the region of interest. Variations in charge conditioning temperature, projectile weight and projectile seating distance would be the parameters to assure results from this study would be at an acceptable pressure (well under the ~700 MPa pressure limit for the tube), potentially useful both to the modeling community and to the community more directly interested in any growth potential for the performance of solid propellant guns.

## 2. INITIAL TESTING

### 2.1 Description of Components.

All testing was conducted at the Sandy Point Firing Facility (Range 18) located at the Ballistic Research Laboratory (BRL), Aberdeen Proving Ground, Maryland. As previously indicated, a 120-mm, ballistic tube similar in design to an XM-25 Cannon with 6304 mm of inbore travel (1524 mm more than the standard 120-mm, M256 Cannon) was used for all the tests. The gun tube was instrumented with four of the five pressure gages in the chamber: two each, 100 degrees apart at 95 mm, and two each, 70 degrees apart at 489 mm as measured from the rear face of the tube. Redundancy at the breech and forward chamber positions was incorporated into the cannon because of the possibility of losing a gage at the high pressures expected for these firings. The gage at the center of the chamber (286 mm) was not used. To measure pressure at discrete downtube locations, eleven gages were located at 768 mm, 908 mm, 1048 mm, 1289 mm, 1530 mm, 2292 mm, 3054 mm, 3816 mm, 4578 mm, 5340 mm and 6102 mm. An M174 Recoil Mechanism in conjunction with the upper carriage from a 155-mm, M59 Gun was used to mount the APG Medium B Sleigh which housed the 120-mm, ballistic cannon. Projectile displacement was determined by using a 15-GHz doppler radar to measure projectile motion both within and 10 metres beyond the gun muzzle. Projectile in-air velocity was calculated by using the distance between a known time interval just after the projectile exited the gun tube using both the 15-GHz inbore and 10-GHz Weibel radars. Ignition delay was determined by using, as zero time, the application of the firing voltage to either a M125 or a XM123 electrical primer. Generally, the data were recorded in real time by the Ballistic Data Acquisition System (BALDAS) under the control of a PDP 11/45 minicomputer. If the data were not recorded online because of some unusual ignition delay or computer malfunction, they were later digitized from an analog tape recording made of each test firing. A schematic of the 120-mm, ballistic cannon is shown in Figure 1, along with the locations of the 14 axial pressure port locations.

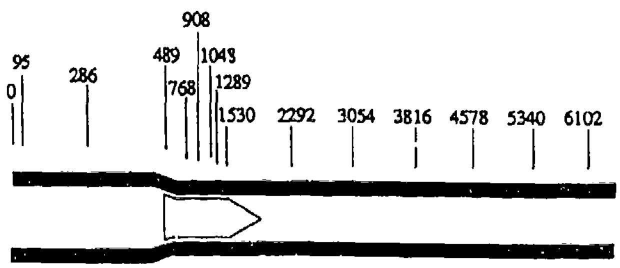


Figure 1. Locations of Pressure Transducers in the 120-mm High Velocity Gun.

Two Photec high-speed cameras and one smear camera were used to record the initial free flight of the projectiles for selected firings. The schematic layout of the firing barricade in Figure 2 shows the positions of the three cameras, the inbore and downrange radar units and the reflector mediums for both radar systems. Primary concern was in optimizing the 15-GHz doppler signal from the projectile to the radar unit so that accurate muzzle velocity could be calculated. The downrange Photec and smear cameras were to determine if unburnt propellant was expelled from the cannon and if the projectile survived the high velocity environment.

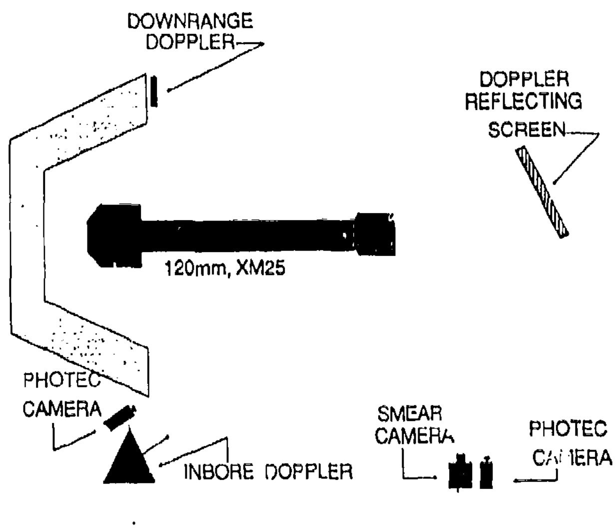


Figure 2. Schematic Layout of the Firing Barricade.

Although several projectile configurations were used during the course of this program, the projectile shown in Figure 3, with length modifications depending on C/M ratio, was chosen as the standard because it consistently withstood the inbore forces during the crucial portion of the ballistic cycle. The

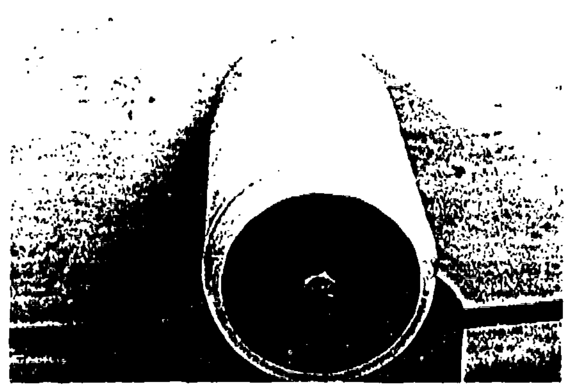

Figure 3. Polypropolux Projectile Configuration.

projectiles were made of a polypropolux plastic. This choice of material provided an inexpensive approach to meeting the low weight requirement as well as facilitating incorporation of a standard obturator configuration into the projectile design.

The propelling charges employed the conventional JA2 formulation used in the 120-mm tank gun. The propellant configuration for Series A and B used a high progressivity/high density (HPD) concept known as partially cut (PC) stick propellant. Use of nearly any stick geometry results in a higher loading density and provides natural flow channels to minimize pressure gradients within the charge during flamespread. However, the use of the traditional, slotted-stick geometry (Figure 4, left) provides a slightly regressive burning profile, not allowing efficient use of the higher loadable charge weight. Unslotted stick configurations, usually necessary for more progressive, multiperforated geometries, suffer from problems with overpressurization within the perforation leading to stick fracture (Robbins 1984; Robbins 1988). The PC configuration circumvents this problem by providing lateral venting of the perforations at the required spacing to avoid pressure build-up (Figure 4, right). Very likely, the sticks separate into short segments sometime early in the interior ballistic cycle, but all testing to date indicates that this occurs after flamespreading is complete, thereby not compromising the high longitudinal permeability required for use of a simple base ignition system.

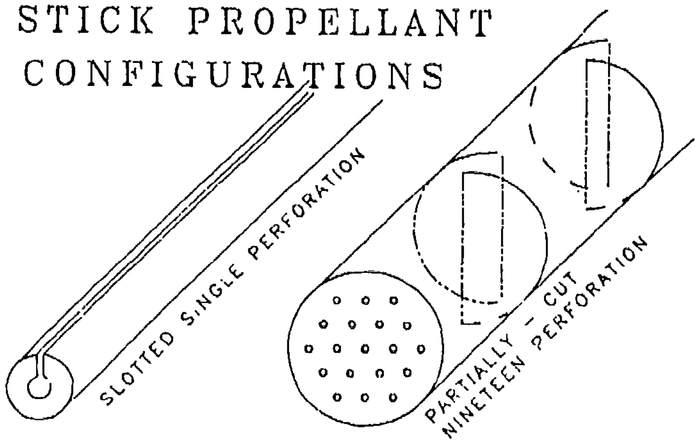


Figure 4. Venting Techniques for Different Stick Propellant Geometries.

The overall charge for Series A employed a BRL-designed charge of axially-aligned JA2 stick propellant and a projectile seated in the forcing cone in the standard manner; for Series B the same base charge was used, but one of three additional charge increments, depending on the final initial seating distance of the projectile, was added after the projectile was forcibly seated forward of the forcing cone in the gun. Both charge configurations are represented by the schematic in Figure 5. Both series employed a standard 120-mm stub base for holding an ignition system consisting of the XM123 stub primer surrounded by a cloth donut containing 100 g of Class 1 black powder. No combustible or inert case was used to hold the propellant. The projectile and charge were separately loading into the gun.

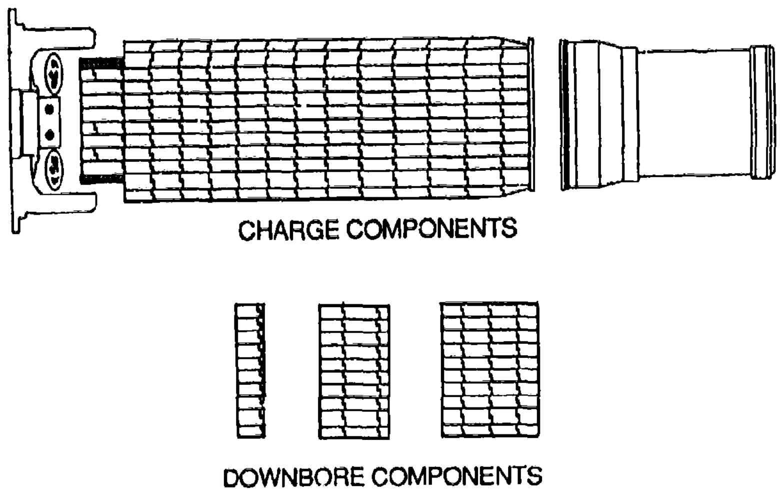


Figure 5. Overall Charge Configuration for Stick Propellant, Standard and Downbore Loading.

The propellant used for Series C was granular, hexagonal, 19-perforated JA2 contained in a noncombustible cartridge case (Figure 6). Although the pressure loss incurred by using an inert cartridge case was significant, the necessary pressure needed to impart sufficient energy to a low mass projectile and still achieve velocities in the 2.0 - 2.7 km/s range was obtainable by conditioning the propellant at a high temperature. Nitrocellulose cases were not used so as to minimize unknown or poorly defined case parameters as input to the interior ballistic code. Experiments are ongoing to better defined these parameters for systems using nitrocellulose containers. To eliminate the possibility of pressure wave formation, ignition of the highly compacted granular charge was accomplished with a M125 primer extending well into the charge.

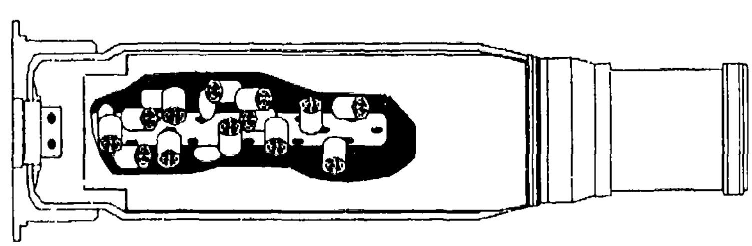

Figure 6. Overall Charge Configuration for Granular Propellant, Standard Loading.

Further details of the gun, projectile, and charges for each of the three series are tabulated in Table 1.

Table 1. Gun, Projectile and Charge Characteristics for Series A, B and C

| Characteristics | C/M | Temp ($^{o}C$) | Series A | Series B | Series C |
|---|---|---|---|---|---|
| Gun Caliber | | | (------------120 mm | -------------) | |
| Inbore Travel (mm) | | | 6304 | varies | 6304 |
| Chamber Volume (cc) | | | 9631 | varies | 9631 |
| Nominal Projectile Weights (kg) | 3 | 21 | 3.25 | 3.35 | 2.66 |
| | 5 | 21 | 1.98 | 2.27 | 1.65 |
| | 6 | 21 | N.A. | 1.98 | N.A. |
| Stick Propellant Weight (kg) | 3 | 21 | 9.85 | 9.85 + 0.23 | N.A. |
| | 5 | 21 | N.A. | 9.85 + 1.09 | N.A. |
| | 5 | 63 | 9.85 | N.A. | N.A. |
| | 6 | 21 | N.A. | 9.85 + 1.57 | N.A. |
| Granular Propellant Weight (kg) | 3 | 21 | N.A. | N.A. | 8.05 |
| | 5 | 63 | N.A. | N.A. | 8.05 |
| Sidewall Type | ((conditioned at | | None | None | Inert |
| Primer Type | the temperature | | XM123 | XM123 | M125 |
| Basepad Type | of the propellant)) | | --Black powder-- | | None |

Stick propellant (RAD-792-38) web was 1.82 mm; granular propellant (RAD-792-43) web was 1.40 mm; black powder basepad was 100 g of Class 1

## 3. RESULTS AND DISCUSSION

### 3.1 Firing Results, Series A, Stick Propellant, Standard Loading.

Before any rounds were fabricated, a loading assessment was made for the maximum amount of stick propellant that could be loaded into the chamber of the ballistic tube without affecting system integrity (9.85 kg). Since no nitrocellulose (NC) or inert case was used with the stick configurations, considerably more stick propellant could be loaded into the chamber than with a standard 120-mm charge. Prior to fabricating the charge, chamber length measurements were taken to insure that charge length would be slightly less than the chamber length when a projectile was seated in the forcing cone. As shown in Table 1, the loading weight compatible for both temperature conditions was 9.85 kg. Firing results for the series are listed in Table 2.

Table 2. Experimental Firing Results, Series A, Stick Propellant, Standard Loading.

| ROUND NO. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Projectile Weight (kg) | 1.98 | 1.98 | 1.98 | 3.25 | 3.24 | 3.24 |
| Projectile Temperature ( $^{o}C$) | 63 | 63 | 63 | 21 | 21 | 21 |
| Projectile Seating* (cm) | 52.1 | 52.1 | 52.1 | 52.1 | 52.1 | 52.1 |
| Propellant Weight (kg) | 9.85 | 9.85 | 9.85 | 9.85 | 9.85 | 9.85 |
| Propellant Temperature ( $^{o}C$) | 63 | 63 | 63 | 21 | 21 | 21 |
| C/M Ratio | 5.04 | 5.04 | 5.04 | 3.07 | 3.08 | 3.08 |
| Ignition System | ----XM123 Primer plus 100 g--- of Black Powder, Class 1 | | | | | |
| Sidewall Case | --------No Case used--------- | | | | | |
| Maximum Pressures at Gun Ports (see Figure 1 for port positions) | | | | | | |
| P1 | 680 | 681 | 668 | 548 | 551 | 561 |
| P3 | 680 | 679 | 664 | 548 | 547 | 559 |
| P4 | 662 | 671 | 660 | 543 | 542 | 544 |
| P4A | 650 | 659 | 651 | 515 | 520 | 527 |
| P5 | 594 | 612 | 585 | 515 | 520 | 515 |
| P5A | 551 | 566 | 543 | 464 | 495 | 470 |
| P6 | 529 | 522 | 495 | 451 | 488 | 445 |
| P7 | 287 | 359 | 343 | 298 | 312 | 304 |
| P8 | 237 | 253 | 288 | 222 | 236 | 239 |
| P9 | 212 | 230 | 191 | 197 | 203 | 193 |
| P10 | 145 | 167 | 175 | 153 | 141 | 150 |
| Pressure Ratios (breech/base) at Downgage Positions | | | | | | |
| P4 | 2.60 | 2.14 | 2.75 | 2.06 | 1.74 | 1.35 |
| P4A | 2.56 | 2.37 | 2.15 | 1.94 | 1.99 | 1.99 |
| P5 | 3.38 | 3.87 | 3.39 | 2.79 | 2.76 | 2.67 |
| P5A | 3.78 | 2.78 | 3.67 | 2.04 | 2.91 | 2.28 |
| P6 | 3.32 | 3.37 | 3.06 | 2.42 | 2.96 | 2.54 |
| P7 | 3.13 | 3.42 | 4.11 | 3.53 | 3.45 | 3.24 |
| P8 | 3.07 | 3.19 | 3.37 | 2.90 | 2.93 | 2.89 |
| P9 | 3.73 | 4.63 | 3.53 | 2.96 | 2.87 | 2.68 |
| P10 | 3.70 | 3.56 | 3.17 | 2.63 | 2.96 | 2.40 |
| Doppler Velocity** (m/s) | 2686 | 2678 | 2666 | 2278 | 2272 | 2273 |
| Time to 7 MPa (ms) | 1.8 | 3.0 | 8.8 | 5.3 | 14.1 | 4.9 |
| Time to Muzzle (ms) | 6.9 | 8.2 | 14.2 | 11.3 | 19.9 | 10.9 |

*Projectile seating is from rear face of tube
**Velocity in air one meter from the gun muzzle

The desired goal was for the experimental peak pressure to be around 650 MPa for the rounds built with both a C/M ratio of 3 and 5. Based on initial computer simulations using data from past firings and the charge data from Table 1, conditioning temperatures that would meet this pressure goal were estimated to be 21° C and 63° C, respectively, for the C/M of 3 and 5. Rounds were conditioned for at least 24 hours prior to firing. All projectiles were conditioned at 21° C to insure proper seating in the gun forcing cone interface.

A summary of averaged firing results for the C/M of 3 and 5, along with best post firing simulations provided by BRL ballisticians is shown in Table 3. The simulations are from the IBRGA, a modified lumped-parameter code using both the standard Lagrange gradient (Anderson and Fickie 1987) and a new pressure gradient to account for the effects of chambrage and two-phase flow effects (Robbins and Keller 1988), and XNOVAKTC, a two-phase flow code (Gough 1980). For all simulations, input data were based on parameters shown in Table 2.

Table 3. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series A).

| Type of Data | C/M | Breech Pressure (MPa) | Muzzle Velocity (m/s) | Displacement at Peak Pressure (mm) |
|---|---|---|---|---|
| Ballistic Tube | 3 | 553 | 2274 | 1270 |
| (Experimental)* | 5 | 676 | 2677 | 1183 |
| IBRGA - Lagrange | 3 | 767 | 2371 | 579 |
| Gradient | 5 | 1028 | 2745 | 683 |
| IBRGA - RGA | 3 | 562 | 2219 | 1058 |
| Gradient | 5 | 697 | 2524 | 1249 |
| XNOVAKTC | 3 | 553 | 2266 | 1364 |
| | 5 | 674 | 2648 | 1191 |

*Chamber volume for these rounds was 9631 cc

Experimental results for the two series with a C/M of 3 and 5 yielded a maximum pressure average of 553 MPa and 676 MPa, respectively. The experimental pressure of 553 MPa for the series at 21° C was much lower than anticipated from calculations done previously on IBRGA. As a result, the desired goal of comparing results at the same overall peak pressure for the two different C/M ratios was not realized.

The smaller than expected experimental pressure for the 21° C firings from that originally predicted demonstrates the importance of enlarging upon the experimental data base to define which parameters affect ballistic performance. Apparently, small changes in propellant weight, initial charge positioning in the gun, lack of accurate temperature burning rate data, information on the effects of PC on propellant functioning, etc., all affect the experimental pressure not yet accurately simulated by the ballistic codes. How the codes handle these variables at high C/M ratios is especially important since the codes seem to be more sensitive to small changes in initial input than at lower C/M ratios.

One of the major concerns from this and the following two firing series was accurate measurement of inbore pressures, projectile position and muzzle velocity, all highly dependent on projectile integrity. Smear photographs (Figure 7) taken 15 meters in front of the gun revealed no sign of breakup for most of the projectiles tested. For the firings at 63$^{\circ}$ C, severe attenuation of the radar signal believed to be caused by propellant gases leaking by the projectile significantly limited the ability to determine projectile position. Whether the magnitude of gas blowby was sufficient to significantly alter downbore resistance and thus projectile displacement from that predicted by the codes has not been ascertained.

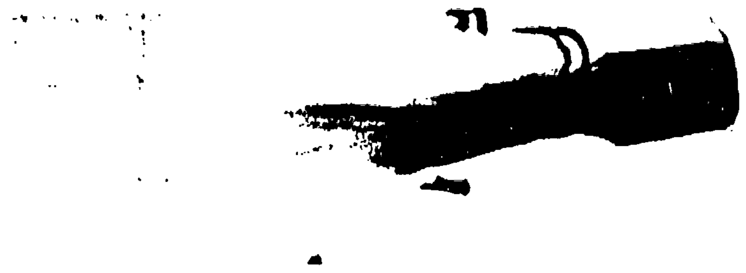

Figure 7. Smear Photograph of Polypropolux Projectile.

### 3.2 Firing Results, Series B, Stick Propellant, Inbore Loading.

Since the same stick charge as in Series A was used for Series B, the maximum amount of stick propellant that could be put in the chamber of the ballistic tube was 9.85 kg. To change the C/M ratios and not compromise system integrity, adjustments were made to both the initial seating distance of the projectile and the projectile weight, as well as the amount of additional charge that could be placed in the gun bore. Since changing projectile seating and adding more propellant were of a high risk nature, all firings were done at 21$^{\circ}$ C. From loading studies, a cylinder of propellant slightly less than bore diameter weighed 0.150 kg per cm. Using the loading data and the ballistic code predictions based on the standard input data base from Series A, the additional inbore propellant weight and inbore length needed for the propellant could be calculated. Projectile inbore initial seating was then fixed by these calculations. Thus, loading compatibility for each round was predetermined by assuring that the propelling charge axial dimension was slightly less than projectile seating distance. As in Series A, no nitrocellulose or inert case was used with the stick configurations. The projectile was seated in the gun bore by pushing it forward using a hydraulic cylinder instrumented with a pressure indicator. As the projectile moved forward into the bore, the pressure was monitored and recorded. From these readings, as indicated for the simulations done previously in Series A, a measured but very limited static bore resistance/displacement profile could be determined.

All charges were conditioned at 21° C for at least 24 hours prior to firing; all projectiles were conditioned at 21° C to insure that material expansion due to temperature was not an issue in proper seating in the gun forcing cone interface. Firing results for the series are listed in Table 4. The goal, as in Series A, was to have the peak pressure for the three different C/M's be at 650 MPa.

A summary of averaged firing results for the C/M of 3, 5 and 6, along with predictions provided by the interior ballistician, is provided in Table 5. As in Series A, input parameters for the gun and charges are listed in Table 1.

Experimental results with a charge mass of 10.08 kg (C/M of 3) were essentially the same, with breech pressures of 585 MPa and 584 MPa and in-air velocities of 2283 m/s and 2284 m/s. Projectile seating for the two firings differed by 2 cm; interior ballistic simulations were performed using the average of the two, leading to a predicted maximum chamber pressure of 650 MPa. As in the case of Series A, the experimental pressure was somewhat lower (approximately 10% this time) than the prediction.

Experimental results for a charge mass of 10.94 kg (C/M of 5) were not as consistent. Projectile seating distances for the two rounds again differed by 1.5 cm. Maximum chamber pressures, 627 MPa and 624 MPa, agreed quite well; however, the corresponding in-air velocities were measured to be 2522 m/s and 2480 m/s. It is noted that six of the nine downtube pressure gages yielded higher values for the faster round, suggesting more area under the pressure-travel curve and consistent with a higher overall acceleration profile; however, normal variability in gage response may account for these differences.

At a C/M of 6, only one round was fired because the hydraulic device used for seating the projectile ruptured. The peak pressure of 659 MPa was in the range of the experimentally-planned pressure level of 650 MPa. Muzzle velocity at 2584 m/s was consistent with the higher pressure.

The summary of averaged firing results along with the BRL firing simulations (Table 5), which had the same input data for the gun/projectile interface as that done for Series A, reflects the variability between the codes. Only inputs to reflect projectile seating, charge weight, etc., were modified.

Table 4. Experimental Firing Results, Series B, Stick Propellant, Inbore Loading.

| ROUND NO. | 1 | 2 | 2a | 3 | 3a |
|---|---|---|---|---|---|
| Projectile Weight (kg) | 1.97 | 2.27 | 2.27 | 3.35 | 3.35 |
| Projectile Temperature ( $^{o}$C) | 21 | 21 | 21 | 21 | 21 |
| Projectile Seating* (cm) | 65.9 | 63.7 | 62.2 | 57.2 | 55.2 |
| Propellant Weight (kg) | | | | | |
| In Chamber | 9.85 | 9.85 | 9.85 | 9.85 | 9.85 |
| In Bore | 1.56 | 1.09 | 1.09 | 0.23 | 0.23 |
| Propellant Temperature ( $^{o}$C) | 21 | 21 | 21 | 21 | 21 |
| C/M Ratio | 5.84 | 4.86 | 4.86 | 3.04 | 3.04 |
| Ignition System | -----XM123 Primer plus 100 g----- of Black Powder, Class 1 | | | | |
| Sidewall Case | -----------No Case used---------- | | | | |
| Maximum Pressures at Gun Ports (see Figure 1 for port position) | | | | | |
| P1 | 659 | 627 | 624 | 587 | 584 |
| P3 | 640 | 621 | 604 | 587 | 572 |
| P4 | 633 | 604 | 604 | 580 | 565 |
| P4A | 623 | 592 | 597 | 580 | 545 |
| P5 | 588 | 580 | 570 | 550 | 536 |
| P5A | 606 | 568 | 525 | 511 | 512 |
| P6 | 540 | 516 | 525 | 511 | 480 |
| P7 | 332 | 335 | 340 | 326 | 310 |
| P8 | 223 | 263 | 284 | 226 | 223 |
| P9 | 248 | 196 | 189 | 145 | 150 |
| P10 | 200 | 196 | 189 | 145 | 150 |
| Pressure Ratios (breech/base) at Downgage Positions | | | | | |
| P4 | 1.77 | 2.47 | 2.53 | 2.40 | 1.89 |
| P4A | 2.10 | 3.35 | 1.73 | 2.93 | 3.09 |
| P5 | 2.15 | 3.01 | 2.07 | 3.42 | 2.93 |
| P5A | 2.48 | 2.44 | 2.67 | 2.60 | 3.05 |
| P6 | 2.25 | 4.00 | 2.49 | 2.92 | 2.50 |
| P7 | 2.72 | 4.12 | 3.11 | 4.49 | 3.45 |
| P8 | 2.47 | 3.40 | 2.88 | 3.97 | 2.92 |
| P9 | 2.00 | 2.89 | 3.28 | 3.25 | 2.91 |
| P10 | 2.16 | 4.02 | 3.89 | 2.08 | 2.04 |
| Doppler Velocity** (m/s) | 2584 | 2522 | 2480 | 2284 | 2283 |
| Time to 7 MPa (ms) | 5.8 | 4.9 | 3.7 | 16.9 | 11.3 |
| Time to Muzzle (ms) | 11.3 | 10.4 | 8.9 | 22.9 | 17.2 |

*Projectile seating is from rear face of tube
**Velocity in air one meter from the gun muzzle

Table 5. Experimental and Simulated Data for a Cartridge with a C/M of 3, 5 and 6 (Series B).

| Type of Data | C/M | Breech Pressure (MPa) | Muzzle Velocity (m/s) | Displacement at Peak Pressure (mm) |
|---|---|---|---|---|
| Ballistic Tube | 3 | 586 | 2284 | 1230 |
| (Experimental)* | 5 | 626 | 2501 | 1240 |
| | 6 | 659 | 2584 | 1255 |
| IBRGA - Lagrange | 3 | 744 | 2332 | 714 |
| Gradient | 5 | 757 | 2524 | 746 |
| | 6 | 768 | 2610 | 767 |
| IBRGA - RGA | 3 | 591 | 2209 | 1208 |
| Gradient | 5 | 594 | 2392 | 1276 |
| | 6 | 616 | 2457 | 1378 |
| XNOVAKTC | 3 | 616 | 2312 | 1189 |
| | 5 | 616 | 2492 | 1361 |
| | 6 | 639 | 2581 | 1343 |

*Chamber volume for these rounds was 10281 cc for C/M of 3, 11019 cc for C/M of 5, and 11556 cc for C/M of 6

### 3.3 Firing Results, Series C, Granular Propellant.

As in the previous two series, before any rounds were fabricated, a loading assessment was made for the maximum amount of granular propellant that could be reasonably loaded into an inert 120-mm cartridge case having the same overall dimensions as that of the standard NC case. Components were separately loaded as in the stick configuration so that the seating distance for the projectiles could be measured. After a projectile was seated in the gun, the charge was placed in the chamber to insure system compatibility. As shown in Table 1, the loading weight compatible for both temperature conditions was 8.05 kg. During loading into the gun, the propellant was contained in the inert case with a thin piece of paper taped over the forward cap opening.

Interior ballistic simulations (usually quite reliable for conventional granular propellants) suggested that the desired maximum pressure of 650 MPa was unattainable using available granular propellants for the desired test conditions (C/M's of 3 and 5). However, the use of temperature conditioning appeared feasible to at least bring the maximum pressures for the two C/M levels into the same regime.

All charges for the C/M of 3 and 5 were conditioned at $21^{\circ}$ C and $63^{\circ}$ C respectively for at least 24 hours prior to firing;

all projectiles were conditioned at 21° C to insure that material expansion due to temperature was not an issue in proper seating of the projectile in the gun forcing cone interface.

A summary of averaged firing results for the C/M of 3 and 5, along with simulations provided by the interior ballistic codes, is provided in Table 6. The detailed firing results for the two C/M ratios are shown in Table 7. For these simulations, input data were based on parameters shown previously in Table 2 for the ambient charges. As noted in Table 6, the simulations agree closely with the experimental data for the two codes that include chambrage in their modeling.

The round-to-round variations (Table 7) for pressure and velocity, both at a C/M of 3 and 5 were very small. As previously indicated, pressure was well below the desired goal of 650 MPa, a result that could only have been achieved if the propellant web could have been changed.

Table 6. Experimental and Simulated Data for a Cartridge with a C/M of 3 and 5 (Series C).

| Type of Data | C/M | Breech Pressure (MPa) | Muzzle Velocity (m/s) | Displacement at Peak Pressure (mm) |
|---|---|---|---|---|
| Ballistic Tube | 3 | 440 | 2294 | 1297 |
| (Experimental)* | 5 | 471 | 2587 | 1333 |
| IBRGA - Lagrange | 3 | 575 | 2327 | 674 |
| Gradient | 5 | 631 | 2601 | 728 |
| IBRGA - RGA | 3 | 444 | 2186 | 951 |
| Gradient | 5 | 454 | 2394 | 1092 |
| XNOVAKTC | 3 | 438 | 2305 | 1067 |
| | 5 | 465 | 2589 | 1158 |

*Chamber volume for these rounds was 9631 cc

Table 7. Experimental Firing Results, Series C, Granular Propellant, Standard Loading.

| ROUND NO. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Projectile Weight (kg) | 1.65 | 1.65 | 1.65 | 2.66 | 2.66 | 2.65 |
| Projectile Temperature ( $^{o}$C) | 21 | 21 | 21 | 21 | 21 | 21 |
| Projectile Seating* (cm) | 52.1 | 52.1 | 52.1 | 52.1 | 52.1 | 52.1 |
| Propellant Weight (kg) | 8.05 | 8.05 | 8.05 | 8.05 | 8.05 | 8.05 |
| Propellant Temperature ( $^{o}$C) | 63 | 63 | 63 | 21 | 21 | 21 |
| C/M ratio | 4.88 | 4.88 | 4.88 | 3.03 | 3.03 | 3.03 |
| Ignition System | ---------XM125 Primer-------- | | | | | |
| Sidewall Case | -------Inert Case used------- | | | | | |
| Maximum Pressures at Gun Ports (see Figure 1 for port positions) | | | | | | |
| P1 | 478 | 466 | 468 | 442 | 439 | 440 |
| P3 | 445 | 438 | 441 | 416 | 402 | 417 |
| P4 | 367 | 364 | 371 | 354 | 352 | 357 |
| P4A | 350 | 344 | 346 | 338 | 337 | 338 |
| P5 | 327 | 323 | 322 | 317 | 315 | 313 |
| P5A | 292 | 305 | 304 | 292 | 299 | 308 |
| P6 | 274 | 274 | 268 | 270 | 267 | 270 |
| P7 | 174 | 178 | 172 | 184 | 182 | 184 |
| P8 | 124 | 127 | 118 | 136 | 134 | 135 |
| P9 | 81 | 86 | 85 | 91 | 90 | 91 |
| P10 | 78 | 75 | 77 | 93 | 92 | 84 |
| Pressure Ratios (breech/base) at Downgage Positions | | | | | | |
| P4 | 2.66 | 3.29 | 3.09 | 2.27 | 2.09 | 2.37 |
| P4A | 2.31 | 2.40 | 2.73 | 1.87 | 2.17 | 1.89 |
| P5 | 2.62 | 3.71 | 3.12 | 2.69 | 2.34 | 2.16 |
| P5A | 2.58 | 3.56 | 2.28 | 1.87 | 2.69 | 2.06 |
| P6 | 3.19 | 2.85 | 4.40 | 2.51 | 2.84 | 2.64 |
| P7 | 3.34 | 4.14 | 4.89 | 3.03 | 2.95 | 3.32 |
| P8 | 2.98 | 2.84 | 3.38 | 2.59 | 2.91 | 2.49 |
| P9 | 2.93 | 3.84 | 3.15 | 2.37 | 2.43 | 2.63 |
| P10 | 2.14 | 2.95 | 2.77 | 2.26 | 1.99 | 2.01 |
| Projectile Velocity** (m/s) | 2595 | 2579 | 2586 | 2291 | 2292 | 2300 |
| Time to Muzzle (ms) | 13.5 | 13.0 | 14.9 | 16.4 | 15.9 | 21.9 |

*Projectile seating is from rear face of tube
**Velocity in air one meter from the gun muzzle

## 4. DISCUSSION

Experimental pressure-time data for discrete locations along the gun tube are shown for all rounds in Tables 2, 4 and 7. All rounds fired are shown plotted in Appendix B. Two pressure ports nearest the muzzle could not be used because the gages were consistently destroyed during the firing cycle. Strain gage measurements at these same axial locations to calculate a pressure were not successful. Very high-frequency, superimposed noise on top of the strain records impeded the reduction of the data.

Typical of the pressure-time data are the selected plots of Figure 8 for Series B, C/M of 5, projectile at 21° C and stick propellant at 63° C, with sampling at fifty microseconds per sample (BALDAS) and one microsecond per sample (TAPE), respectively. Pressure data in the chamber (P1 and P3) are not compromised at either sampling rate. For the downtube gages (P6 and P10), the time at which the projectile passes and exposes the gage to gun pressure and the character of the rise is somewhat compromised because of the minimum number of points defining this time interval. However, the absolute value of pressure for these downtube positions is approximately the same.

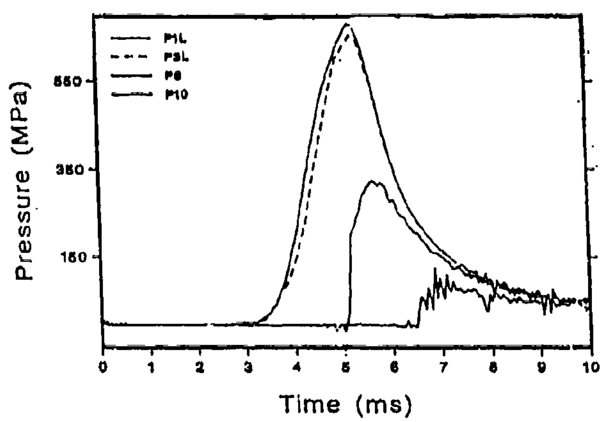


Figure 8a. Fifty (50) microseconds per sample

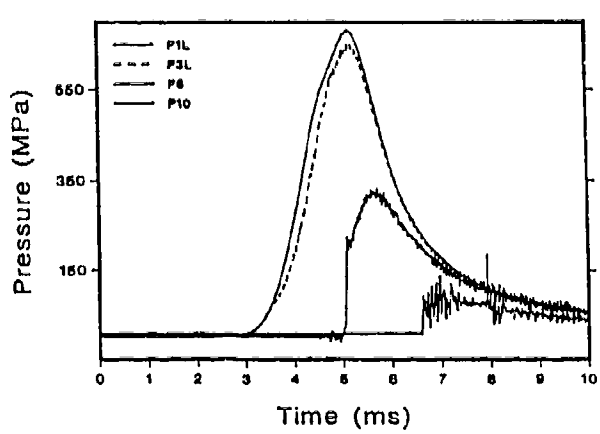


Figure 8b. One (1) microsecond per sample

Figure 8. <u>Typical On-Line Pressure-Time Profiles for Series B, C/M of 5, Stick Propellant at 63° C, Sampling at 50 and 1 us/Sample</u>.

Efforts are being made to improve the techniques for measuring and reducing inbore radar data to provide an online computer comparison of predicted and observed inbore trajectories. From hand-read records of doppler output from analog tape, projectile inbore position can be laboriously determined but not easily compared to that indicated by the data-time record of a downtube pressure and/or strain station which is recorded online. Techniques for obtaining pressures at locations close to the gun muzzle have not been successful, thus limiting the accuracy of the breech to base pressure ratios that are calculated for comparison to simulations. Finally, an effort is ongoing to do an experiment to obtained onboard pressure and acceleration measurements in the regime of C/M's well above unity. However, survivability of onboard gages and electrical components are still a major problem.

## 5. CONCLUSIONS

The current study reinforces the view that chemical propulsion is a viable option for a hypervelocity system. Firings were done that demonstrated that velocities as high as 2.68 km/s with launch masses in the 2 kg range can be obtained with conventional stick propellant gun techniques at conventional pressures in the 120-mm gun. Launch masses of 1.6 kg were in the 2.2 - 2.6 km/s range at pressures below 500 MPa in a 120-mm gun. These results were accomplished using current Army 120-mm gun and charge components.

## 6. ACKNOWLEDGMENTS

The authors wish to acknowledge Mr. W. Donovan for designing the projectiles; Messrs. J. Bowen, J. Hewitt, E. Mark, and J. Tuerk of the Applied Ballistics Branch and R. May and D. Meier of Applied Concepts Corporation for their usual high level of cooperation and support at the branch's Sandy Point Firing Facility; Messrs. A. Pflegel and E. Stilson, Benet Weapons Laboratory, for instrumenting the front of the gun tube with strain patches; Ms. K. Meyers for the technical illustrations used in the paper; and Messrs. R. Mudd and I. Stobie for incisive comments and suggestions in their review of the report.

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# APPENDIX A - Propellant Description Sheets

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PROPELLANT DESCRIPTION SHEET | EXEMPT-PARA 7-2a AR 335-15

| COMPOSITION | DA LOT NUMBER |
|---|---|
| PROPELLANT, JA-2, 19 PERFORATION, HEX | RAD-PE-792-43 |
| SPECIFICATION | PACKED AMOUNT |
| DOD-P-64035, COR LTR SMCRA-EN DTD 11/13/87 | 500 LB |
| AT | CONTRACT NUMBER |
| RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. | DAAA09-86-Z-0003 |

NITROCELLULOSE

| ACCEPTED BLEND NUMBERS | NITROGEN CONTENT | KI STARCH (65.5°C) | STABILITY (134.5°C) |
|---|---|---|---|
| B95248, B95252, B95253, B95254 | | | |
| | MAX ____ % | ____ MIN | ____ MIN |
| | MIN ____ % | ____ MIN | ____ MIN |
| | AVG 13.06 % | 45+ MIN | 30+ MIN |
| | | | EXPLOSION HR |

MANUFACTURE OF SOLVENTLESS PROPELLANT

| FROM | TO | | TIME UNITS | TIME HOURS |
|---|---|---|---|---|
| 145 | 155 | CARPET ROLL AT EXTRUSION | | |
| 160 | 170 | EXTRUSION DIE | | |
| 105 | 115 | FORCED AIR DRY | | 4 |

PROPELLANT COMPOSITION — TEST OF FINISHED PROPELLANT — STABILITY AND PHYSICAL TESTS

| CONSTITUENT | PERCENT FORMULA | PERCENT TOLERANCE | PERCENT MEASURED | TESTS | FORMULA | ACTUAL |
|---|---|---|---|---|---|---|
| NITROCELLULOSE | 59.50 | +/- 2.00 | 58.88 | HEAT TEST @ 120°C | NCC 40' | NCC 60'+ |
| NITROGYLCERIN | 14.90 | +/- 1.30 | 15.54 | NO FUMES | NF 1 h | NF 1 h |
| DIETHYLENE GLYCOL DINITRATE | 24.80 | +/- 1.50 | 24.79 | | | |
| AKARDIT II | 0.70 | +/- 0.20 | 0.72 | TALIANI: | | |
| MAGNESIUM OXIDE | 0.05 | - 0.02 | 0.04 | SLOPE AT 100 mmHg | <1 mmHg/min | 0.350 |
| GRAPHITE | 0.05 | - 0.02 | 0.03 | HOE, cal/g | 1120 NOM. | 1122 |
| TOTAL | 100.00 | | 100.00 | | | |
| | | | | ABSOLUTE DENSITY, g/cc | 1.56 MIN | 1.57 |
| MOISTURE CONTENT | 0.5 | +/- 0.3 | 0.39 | BULK DENSITY, LB/FT³ | INFO | 58.65 |
| ASH CONTENT | 0.3 | MAX | 0.07 | FORM | | HEX |
| METHYLENE CHLORIDE SOLUBLES | 40.4 | +/- 3.0 | 41.67 | NUMBER OF PERFS | | 19 |

CLOSED BOMB — PROPELLANT DIMENSIONS (INCHES)

| | NUMBER | TEMP °F | RELATIVE QUICKNESS | RELATIVE FORCE | | SPECIFICATION | DIE | FINISHED | UNIFORMITY BY MEAN VARIATION,% SPEC | ACTUAL |
|---|---|---|---|---|---|---|---|---|---|---|
| TEST | 792-43 | 90 | 136.59 | 100.62 | | | | | | |
| | | 145 | 149.36 | 101.68 | LENGTH (L) | 0.650 | 0.650 | 0.656 | N/A | 1.39 |
| | | -40 | 130.39 | 100.12 | DIA (D) | 0.430 | 0.453 | 0.434 | N/A | 0.84 |
| | | | | | PERF (d) | 0.020 | 0.019 | 0.022 | DATES: | |
| STD | PE-472-138 | 90 | 100.00% | 100.00% | WEB AVG | 0.055 | 0.060 | 0.054 | | |
| | | | | | INNER | N/A | 0.063 | 0.055 | PACKED | 7/88 |
| | | | | | MIDDLE | N/A | 0.062 | 0.053 | SAMPLED | 7/88 |
| | | | | | OUTER | N/A | 0.054 | 0.053 | TEST FINISHED | 8/88 |
| | | | | | DIFF, % | N/A | | 32 | OFFERED | |
| | | | | | L:D | 1.51 | | 1.51 | DESCRIPTION SHEETS | |
| | | | | | D:d | 21.50 | | 19.40 | FORWARDED | 23 Aug 88 |

REMARKS

CLOSED BOMB TEST PERFORMED IN A 700 CC BOMB AT 0.2 GM/CC LOADING DENSITY.

TYPE OF PACKING CONTAINER FIBER DRUM, DWG 9342857

REMARKS

THIS LOT MEETS SPECIFICATION REQUIREMENTS.

| SIGNATURE OF CONTRACTOR'S REPRESENTATIVE | SIGNATURE OF GOVERNMENT ASSURANCE REPRESENTATIVE |
|---|---|
| [redacted] D W Sh[illegible] | Charles N. Galt[illegible] |

ARRCOM FORM 214R 10 AUG 77

1231u

21

PROPELLANT DESCRIPTION SHEET

REPORTS CONTROL SYMBOL
EXEMPT-PARA 7-2a
AR 335-15

PRELIMINARY

| | |
|---|---|
| COMPOSITION<br>PROPELLANT, JA-2, 19 PERFORATION STICK | DA LOT NUMBER<br>RAD-PE-792-38 |
| [illegible]IFICATION<br>[illegible]D-P-64035 AND SMCRA-EN DTD 8-6-87 | PACKED AMOUNT<br>1400 LB |
| MFG AT<br>RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. | CONTRACT NUMBER<br>DAAA09-86-Z-0003 |

NITROCELLULOSE

| ACCEPTED BLEND NUMBERS | NITROGEN CONTENT | KI STARCH (65.5°C) | STABILITY (134.5°C) |
|---|---|---|---|
| B95191, B95192, B95193, B95194, B95195, B95197 | MAX ___ % | ___ MIN | ___ MIN |
| | MIN ___ % | ___ MIN | ___ MIN |
| | AVG 13.08 % | 45+ MIN | 30+ MIN |
| | | | EXPLOSION HR |

MANUFACTURE OF SOLVENTLESS PROPELLANT

| TEMPERATURES, °F FROM | TO | PROCESS | TIME DAYS | HOURS |
|---|---|---|---|---|
| 150 | 155 | CARPET ROLL AT EXTRUSION | | |
| 165 | 165 | EXTRUSION DIE | | |
| 102.5 | 107.5 | DRYING | | 32 |

TEST OF FINISHED PROPELLANT

| PROPELLANT COMPOSITION CONSTITUENT | PERCENT FORMULA | PERCENT TOLERANCE | PERCENT MEASURED | STABILITY AND PHYSICAL TESTS: TESTS | FORMULA | ACTUAL |
|---|---|---|---|---|---|---|
| NITROCELLULOSE | 59.50 | +/- 2.00 | 59.64 | HEAT TEST @ 120°C | INFO | NO CC 60'+ |
| NITROGLYCERIN | 14.90 | +/- 1.00 | 15.26 | NO FUMES | INFO | NF 1 H |
| DIETHYLENE GLYCOL DINITRATE | 24.80 | +/- 1.50 | 24.33 | | | |
| AKARDIT II | 0.70 | +/- 0.20 | 0.58 | TALIANI: | | |
| [illegible]NESIUM OXIDE | 0.05 | - 0.02 | 0.15 | SLOPE AT 100 mmHg | <1 mmHg/min | 0.297 |
| [illegible]PHITE | 0.05 | - 0.02 | 0.04 | HOE, cal/g | 1120 NOM. | 1115 |
| TOTAL | 100.00 | | 100.00 | | | |
| | | | | ABSOLUTE DENSITY, g/cc | 1.56 MIN | 1.59 |
| MOISTURE CONTENT | 0.5 | +/- 0.3 | 0.3 | | | |
| ASH CONTENT | 0.3 | MAX | 0.09 | FORM | CYL. | CYL. |
| METHYLENE CHLORIDE SOLUBLES | 40.4 | +/- 3.0 | 40.14 | NUMBER OF PERFS | 19 | 19 |

CLOSED BOMB

| | LOT NUMBER | TEMP °F | RELATIVE QUICKNESS | RELATIVE FORCE |
|---|---|---|---|---|
| TEST | PE-792-38 | +90 | 120.38 | 99.81 |
| | | +145 | 135.34 | 99.91 |
| | | -40 | 101.65 | 97.46 |
| STD | PE-472-138 | +90 | 100.00% | 100.00% |

REMARKS
FIRED IN NOMINAL SIZE 700cc CLOSED BOMB AT 0.2 g/cc LOADING DENSITY

PROPELLANT DIMENSIONS (inches)

| | SPECIFICATION | DIE | FINISHED | UNIFORMITY BY MEAN VARIATION,% SPEC | ACTUAL |
|---|---|---|---|---|---|
| LENGTH (L) | 21.4 NOM | 21.4 | 21.4 | N/A | N/A |
| DIA (D) | 0.567 NOM | 0.572 | 0.561 | N/A | 1.49 |
| PERF (d) | 0.039 NOM | 0.037 | 0.036 | DATES | |
| WEB | | | | | |
| INNER | 0.062 NOM | 0.071 | 0.061 | PACKED 11/87 | |
| MIDDLE | 0.062 NOM | 0.071 | 0.060 | SAMPLED 10/87 | |
| OUTER | 0.062 NOM | 0.056 | 0.072 | TEST FINISHED 11/87 | |
| AVG. | 0.062 NOM | 0.066 | 0.064 | | |
| DIFF. | N/A | N/A | 8.06 | OFFERED 12/87 | |
| L:D | N/A | N/A | 38.15 | DESCRIPTION SHEETS | |
| D:d | N/A | N/A | 15.58 | FORWARDED | |

TYPE OF PACKING CONTAINER BOX, FIBERBOARD, PPP-B-636J; BAG, BARRIER, MIL-B-117E; BOX, WOOD, MIL-B-2427G

REMARKS

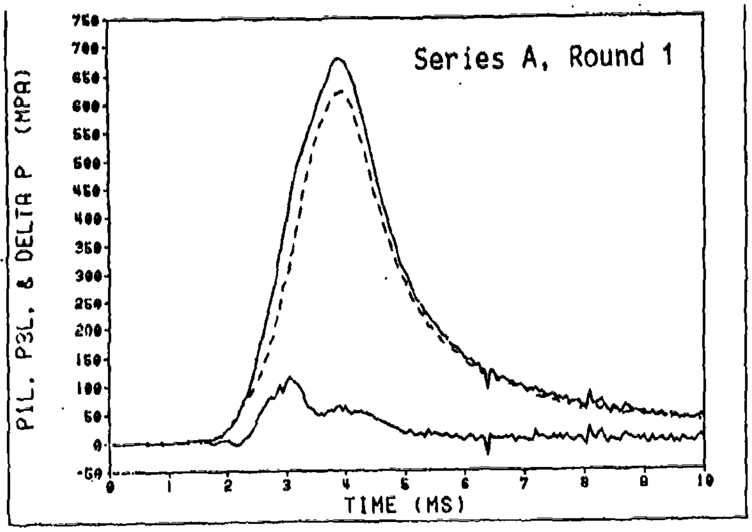
22

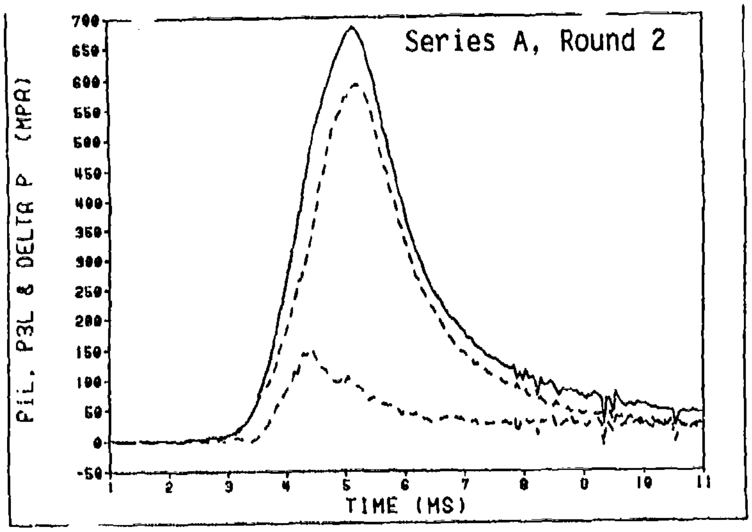
SIGNATURE OF CONTRACTOR'S REPRESENTATIVE
D. W. KIRKPATRICK D. W. Kirkpatrick

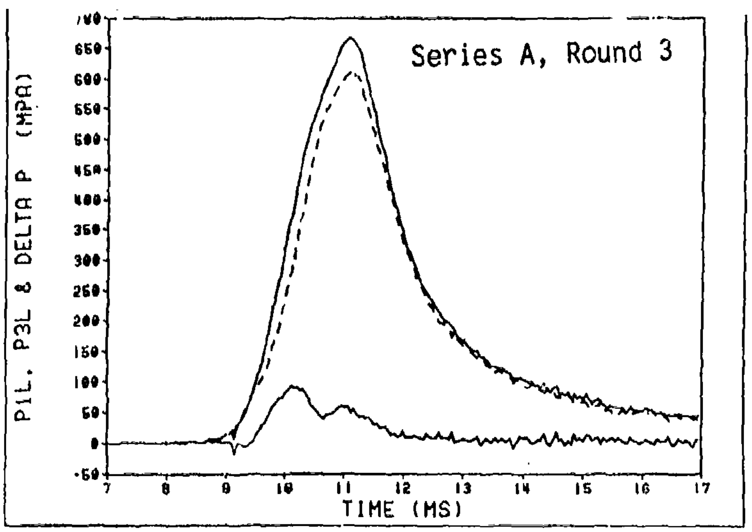
SIGNATURE OF GOVERNMENT ASSURANCE REPRESENTATIVE

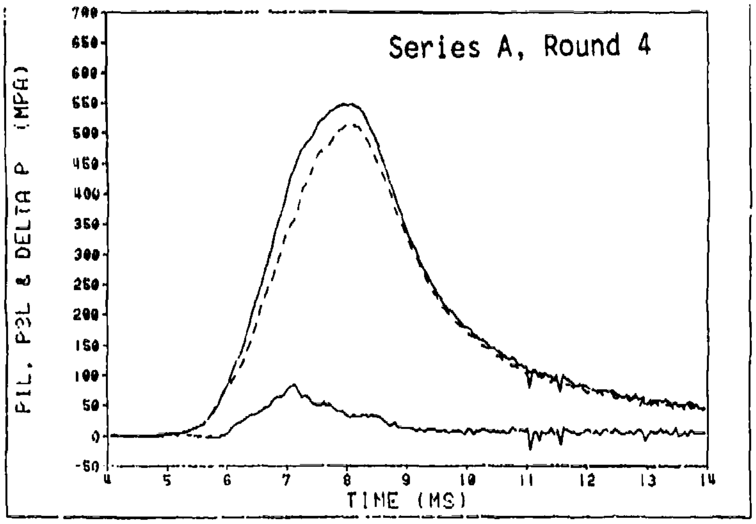
ARRCOM FORM 2148 [illegible]

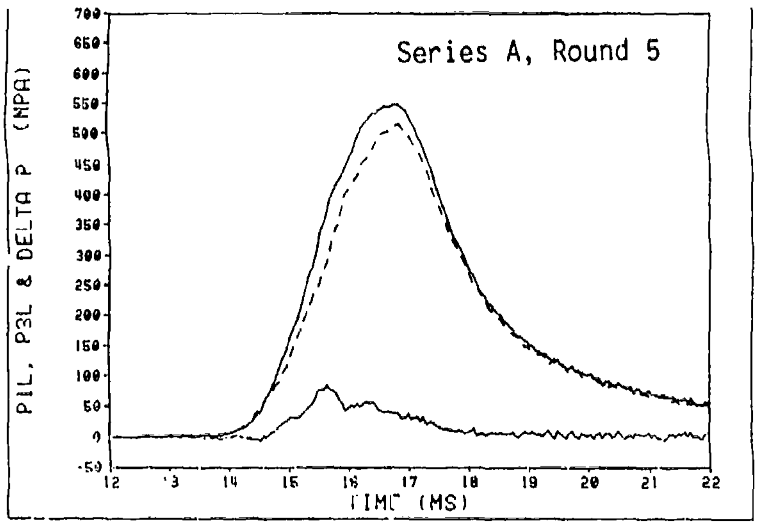
## APPENDIX B - Breech Pressure (Solid Line), Forward Chamber Pressure (Dashed Line), and Pressure Difference Versus Time Plots

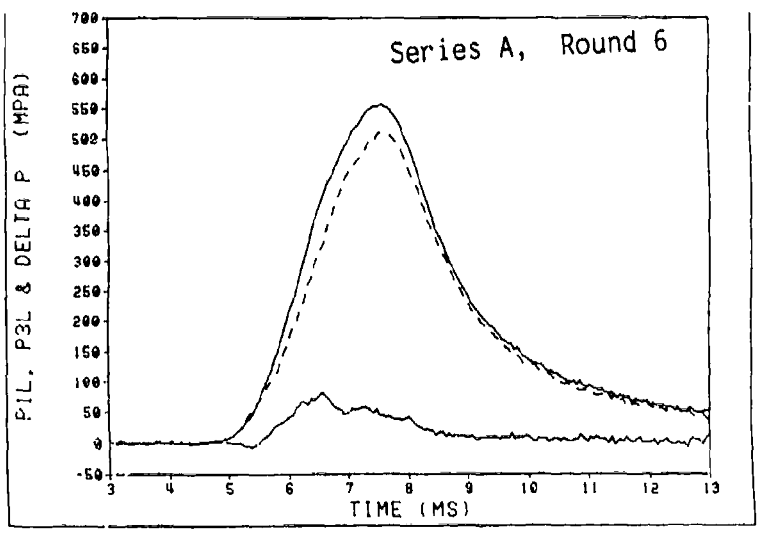

Series A, Round 1
P1L, P3L, & DELTA P (MPA)
TIME (MS)

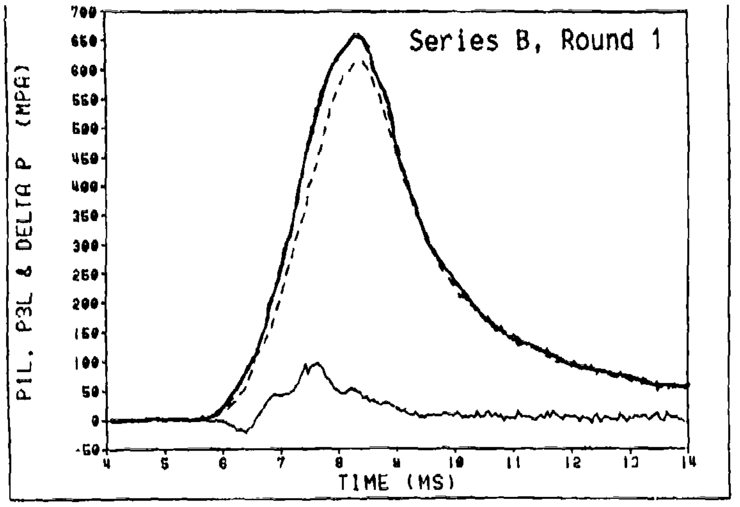

Series A, Round 2
P1L, P3L & DELTA P (MPA)
TIME (MS)

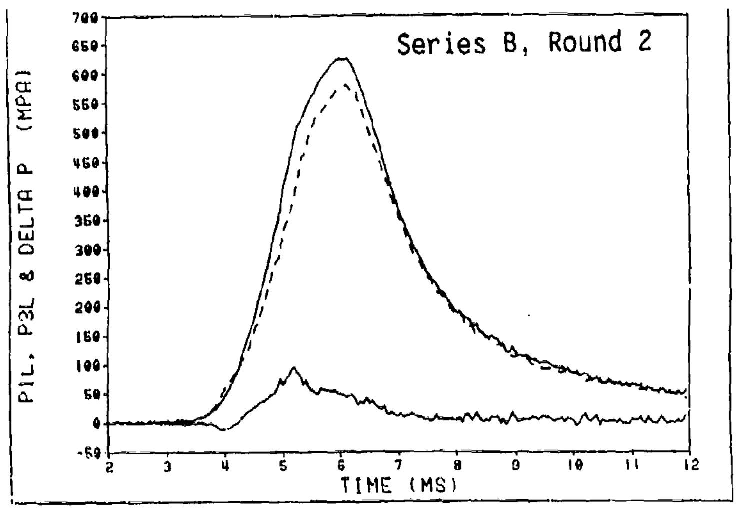

Series A, Round 3
P1L, P3L & DELTA P (MPA)
TIME (MS)

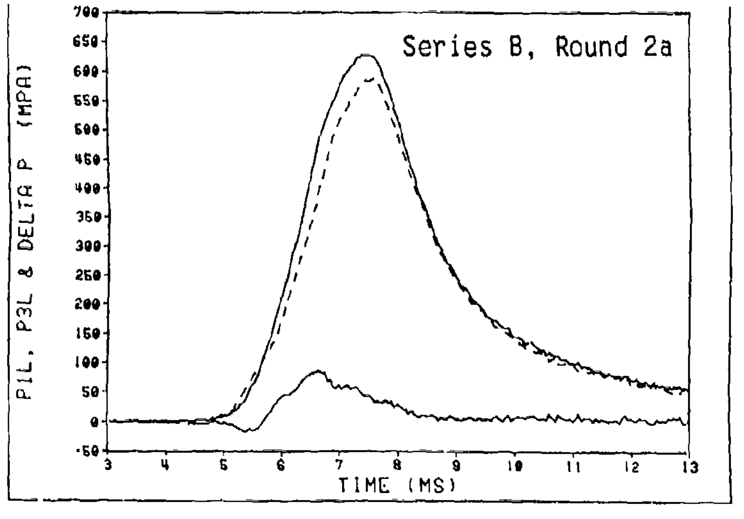

Series A, Round 4
PIL, P3L & DELTA P (MPA)
TIME (MS)

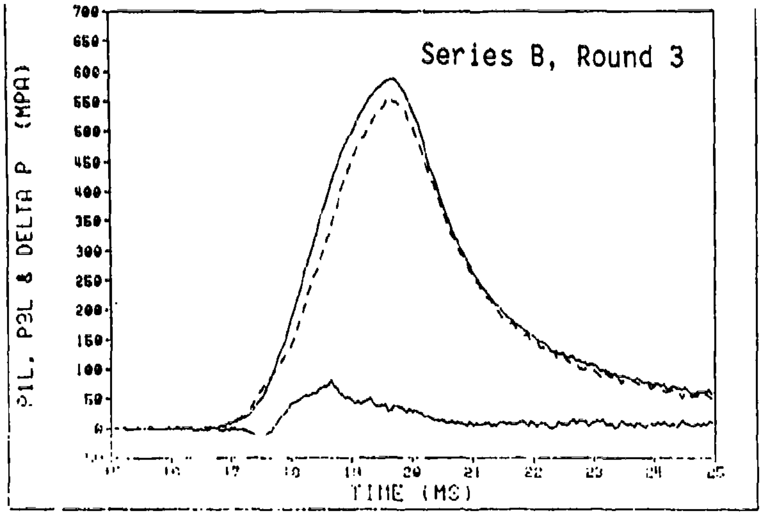

Series A, Round 5
PIL, P3L & DELTA P (MPA)

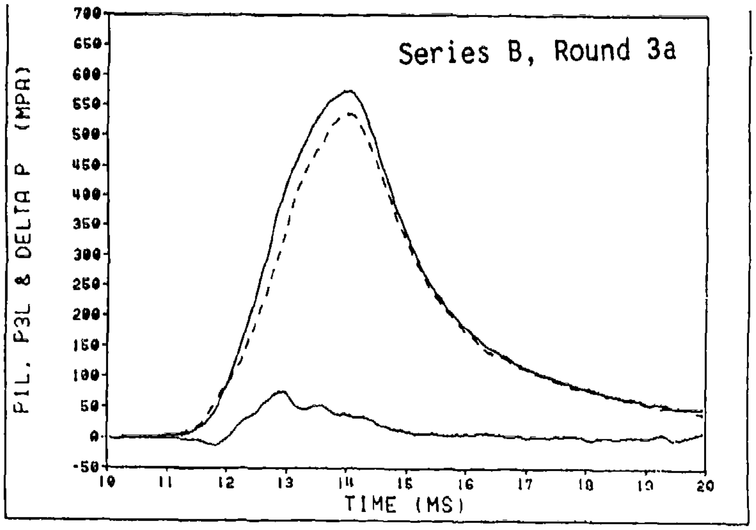

Series A, Round 6
PIL, P3L & DELTA P (MPA)
TIME (MS)


Series B, Round 1
P1L, P3L & DELTA P (MPA)
TIME (MS)


Series B, Round 2
P1L, P3L & DELTA P (MPA)
TIME (MS)


Series B, Round 2a
P1L, P3L & DELTA P (MPA)
TIME (MS)


Series B, Round 3
P1L, P3L & DELTA P (MPA)
TIME (MS)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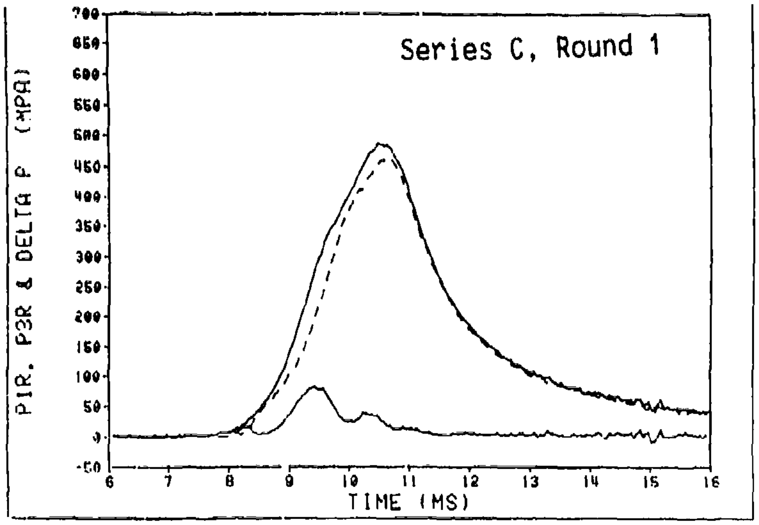
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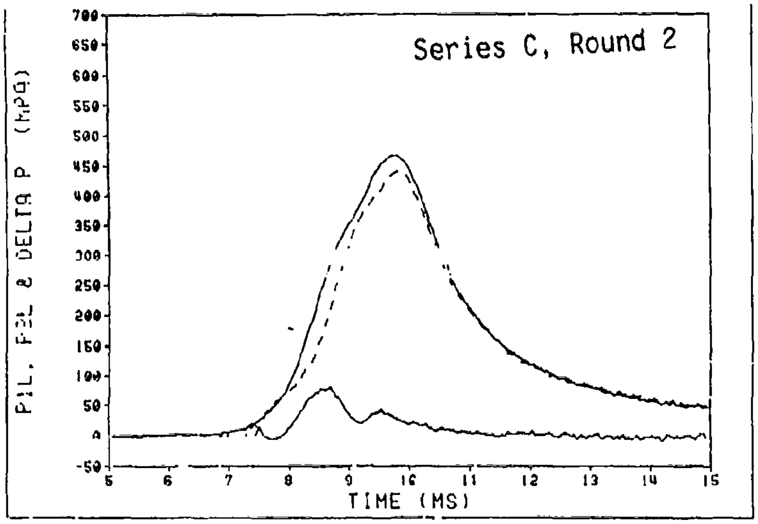
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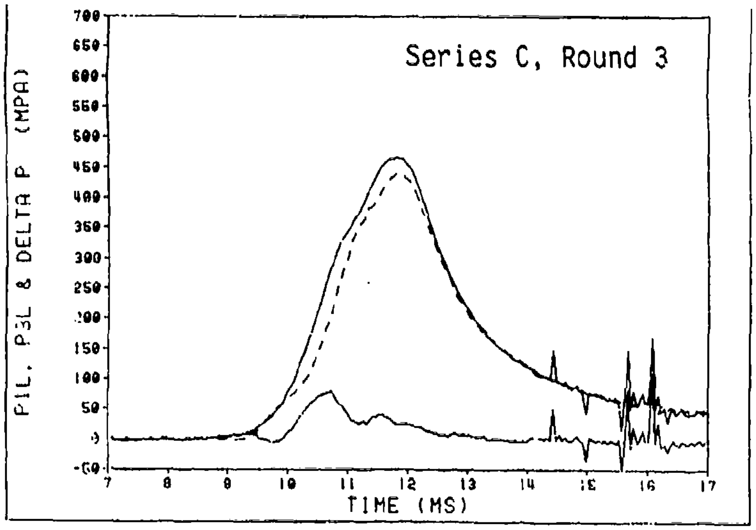
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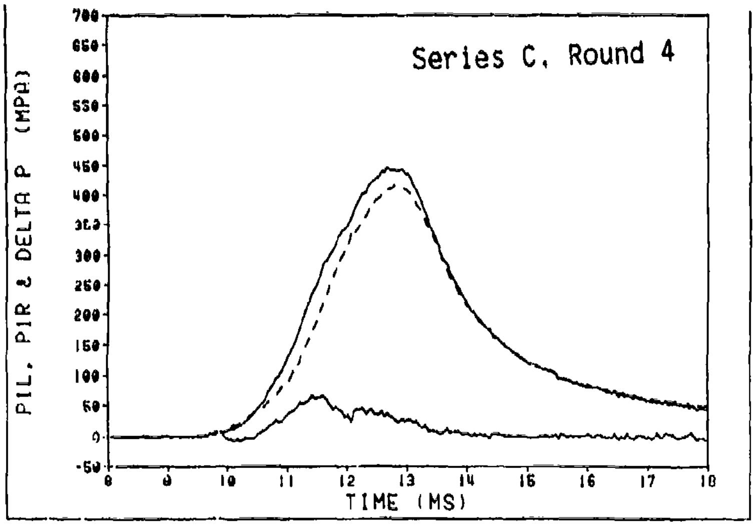

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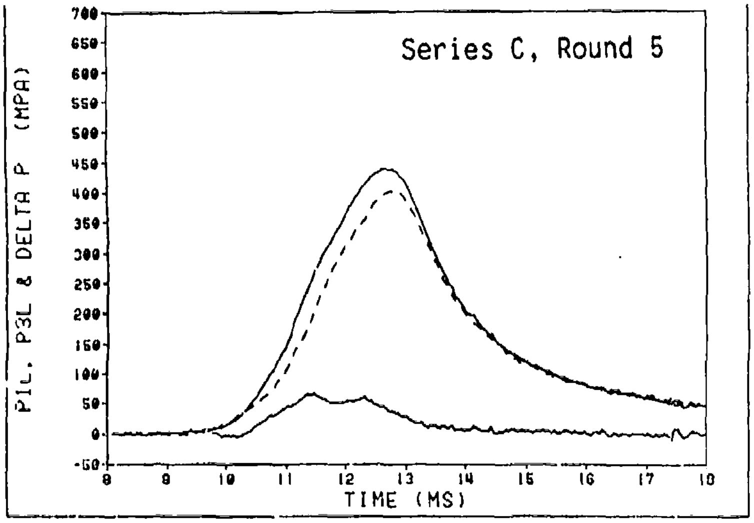

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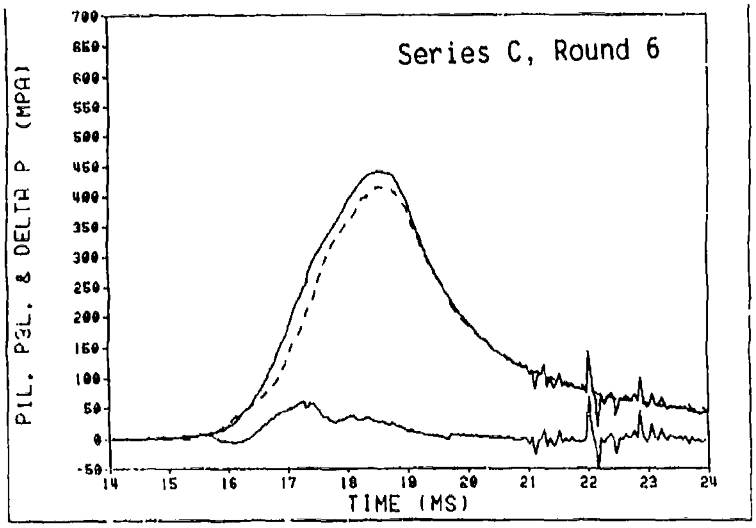

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